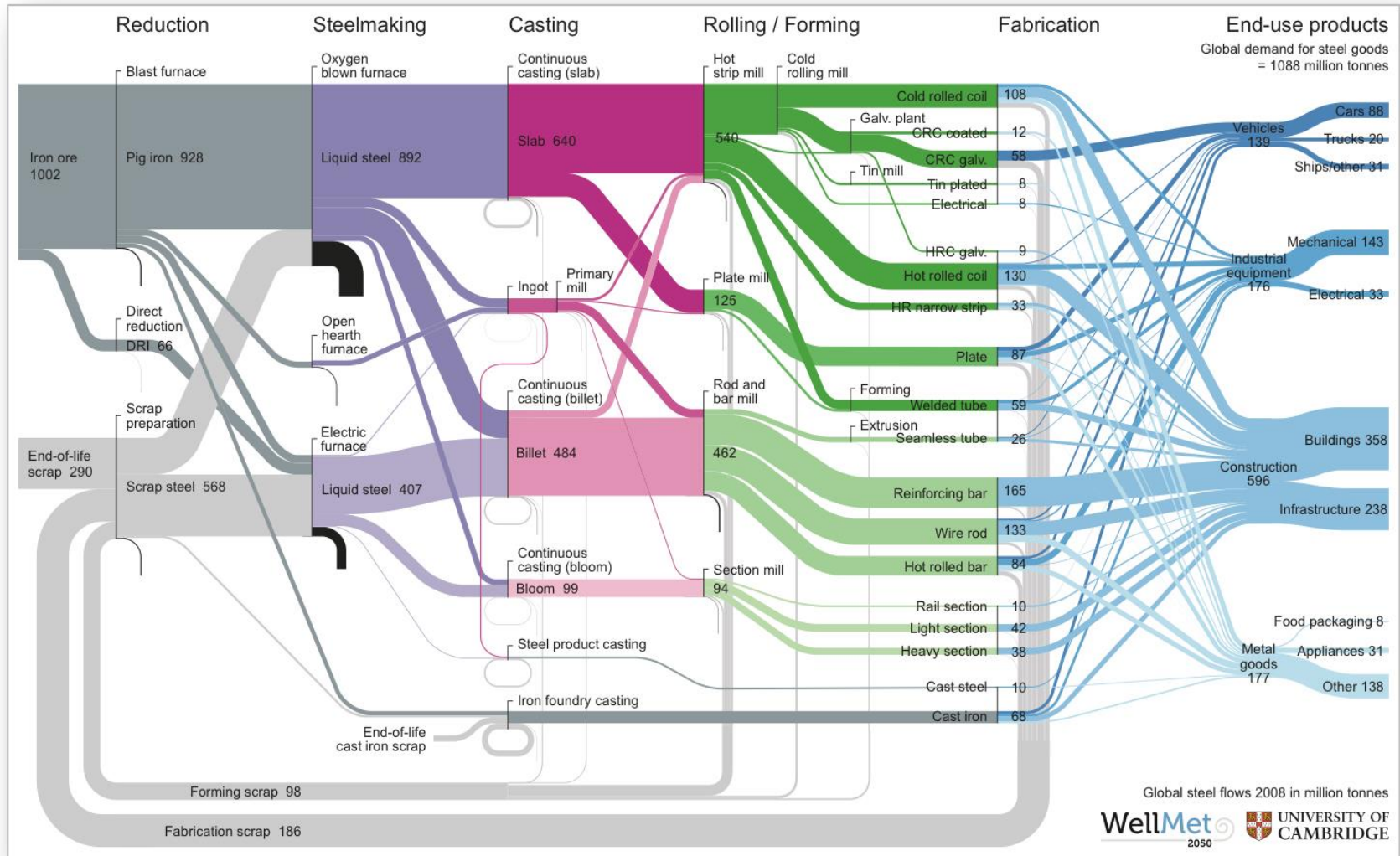




Scrap recycling and material efficiency opportunities

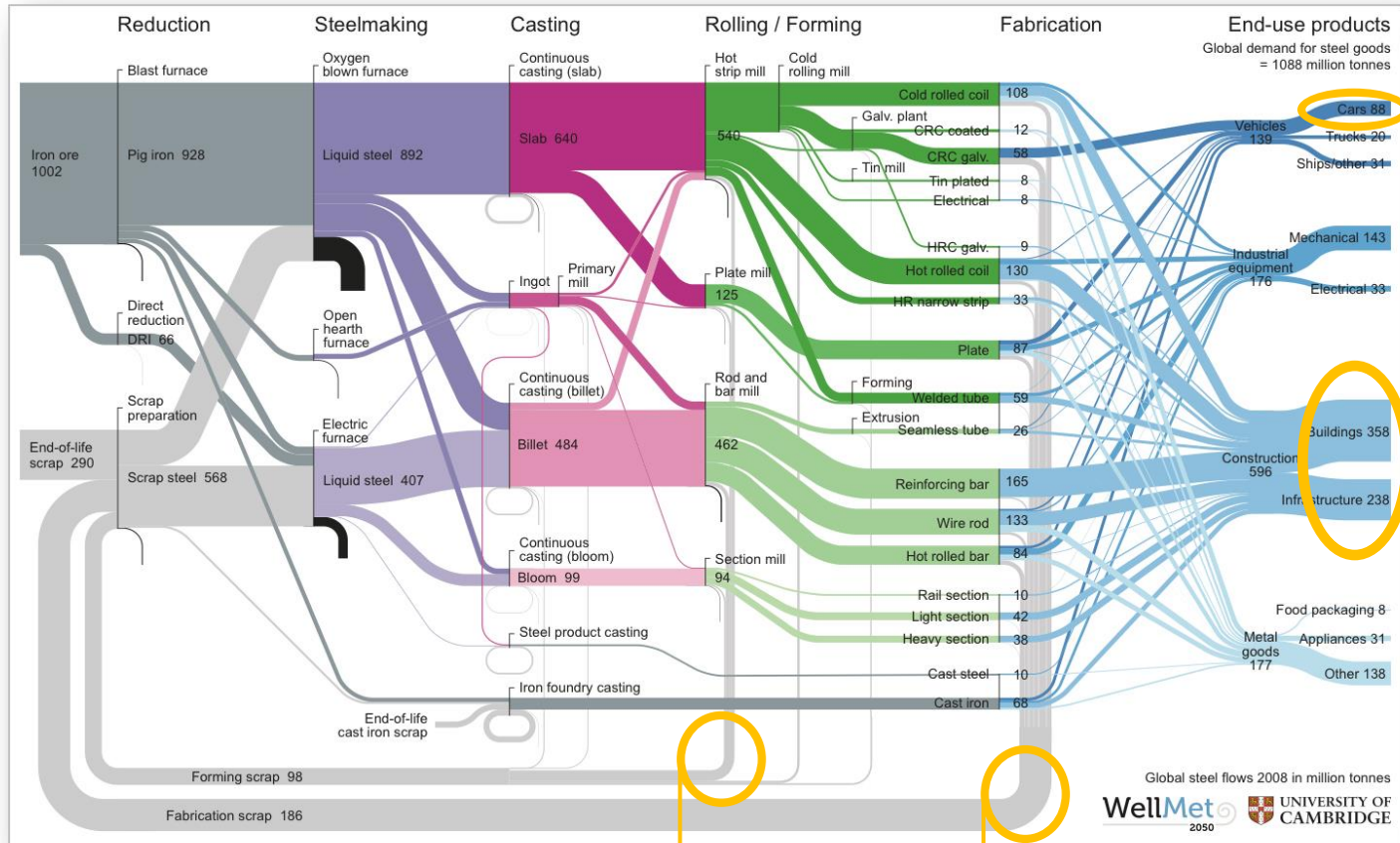
ARPA-E Zero-emission Iron & Steel Workshop
September 1, 2021
Dr. Katie Daehn

The global steel system (2008)



Mapping the global flow of steel: from steelmaking to end-use goods (2012). Cullen et al.

The steel system: prioritizing strategies



Use less metal by design

Re-use metal components, longer lifetime and more intense use

Divert manufacturing scrap

Re-use, longer lifetimes, more intense use

Up to **30%** of steel products could be re-used with minor refurbishment.

The lifespan of many end-use goods could be doubled, to **halve** new steel demand.

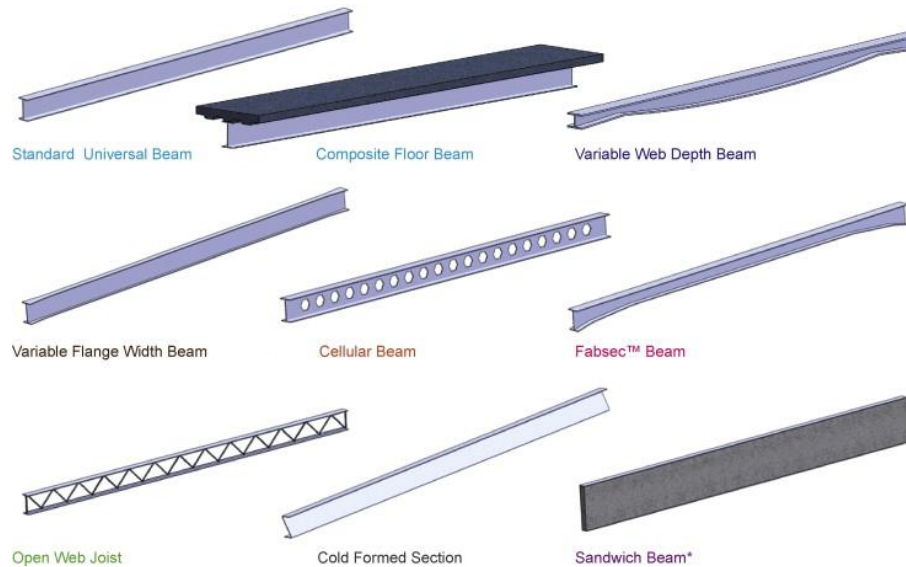
Using products more intensely could decrease demand by **30%**.



Utilization of structural steel in buildings (2014). Moynihan and Allwood.

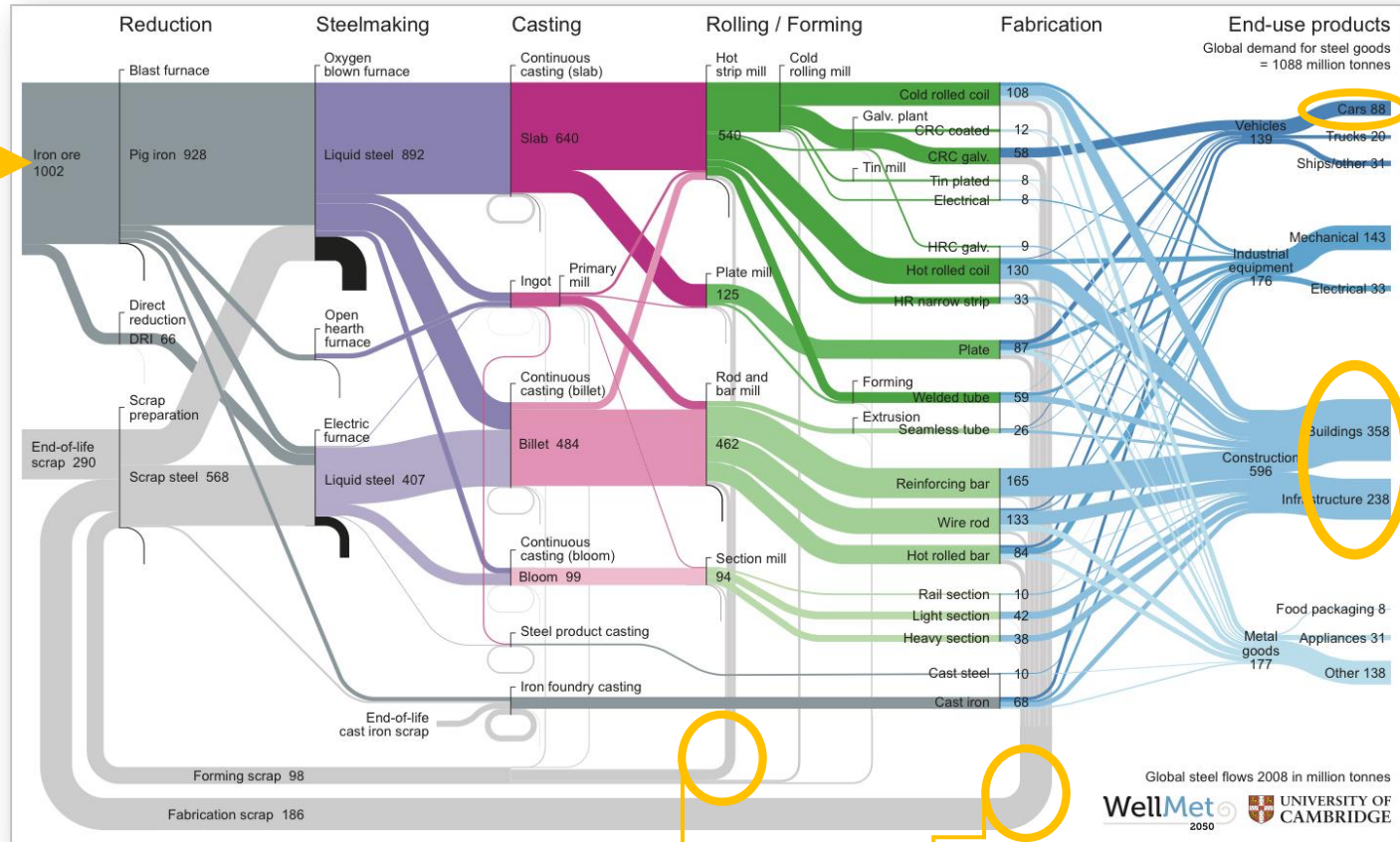
Use less metal by design

If all products were optimized, a **total steel savings of 25%** could be realized (250Mt/yr).



The technical potential for reducing metal requirements through lightweight product design (2011). Carruth, Allwood, Moynihan.

Demand / supply strategies



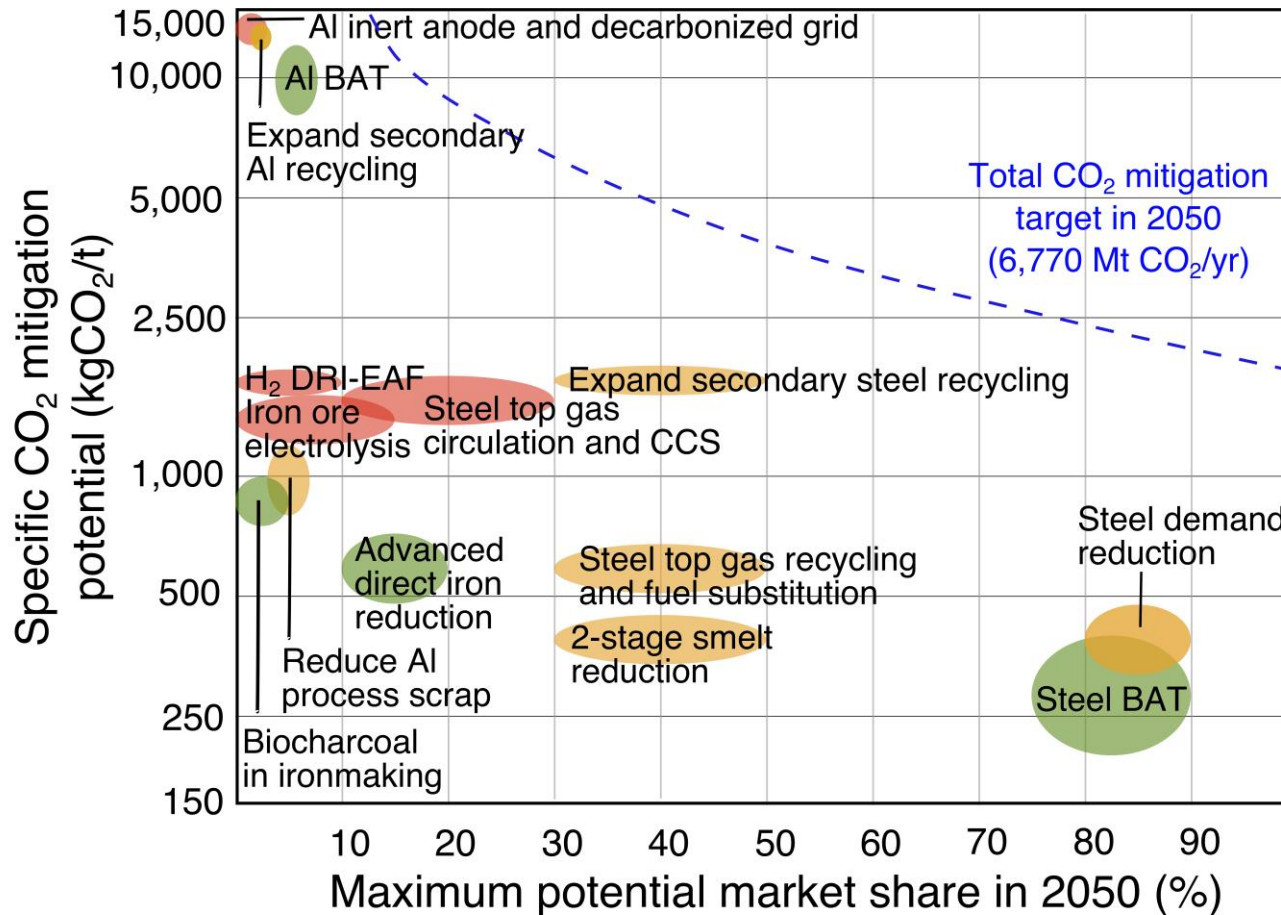
Use less metal by design

Re-use metal components, longer lifetime and more intense use

Divert manufacturing scrap

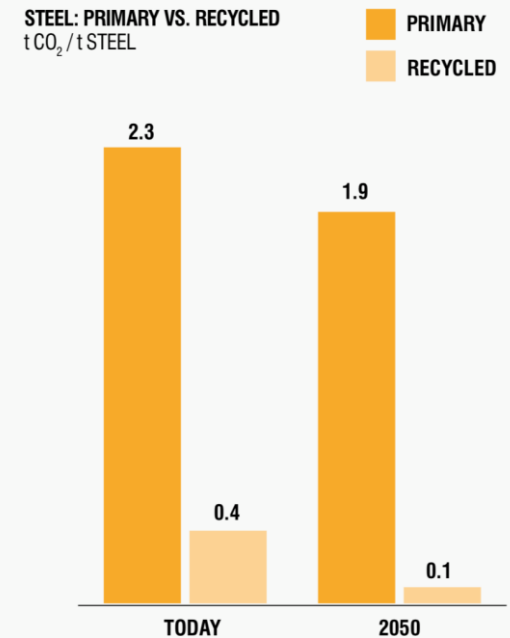
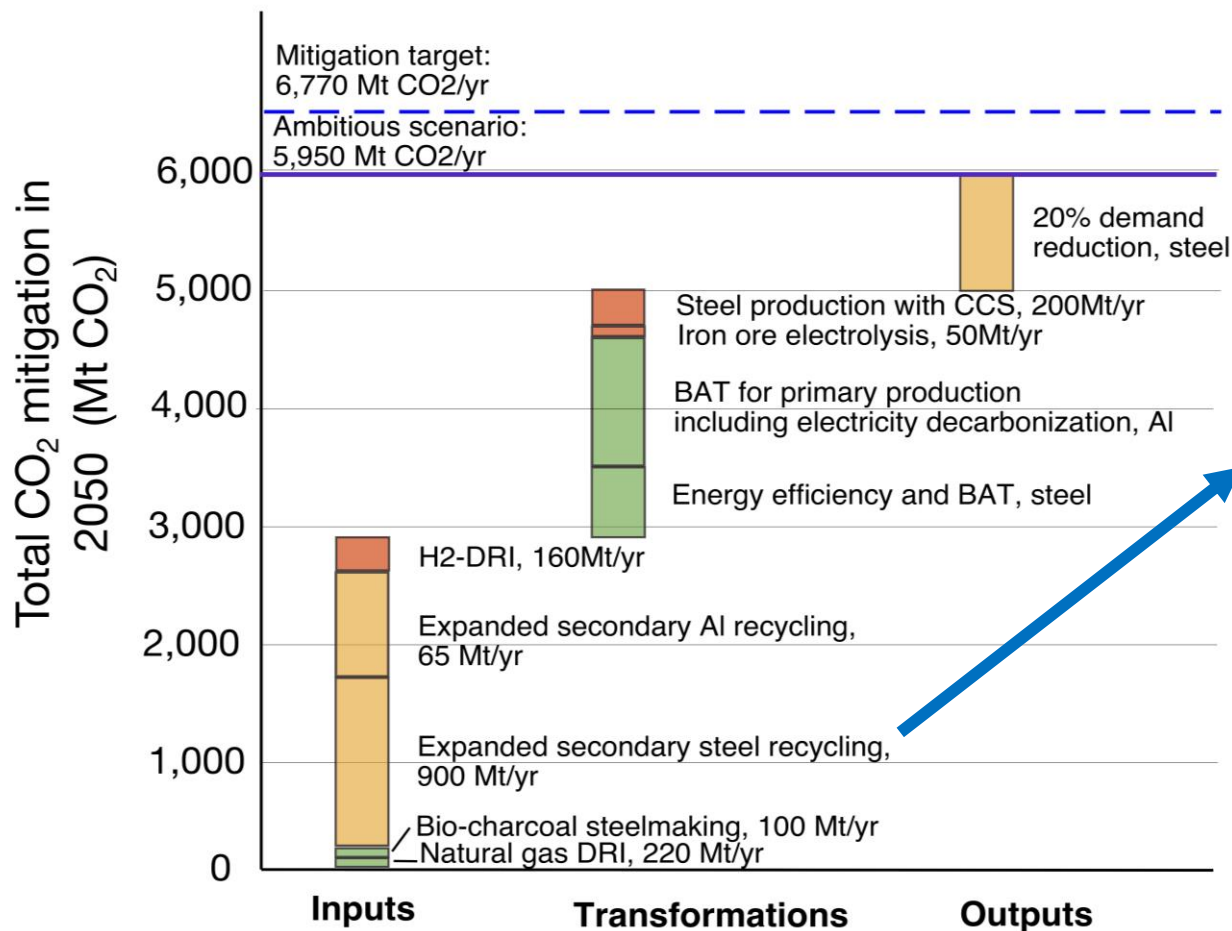
Reduce yield losses

Technologies for decarbonizing metal production



Materials innovations towards decarbonization of materials production, *in press* (2021). Daehn, Ravi, Gregory, Berlinger, Somjit, Olivetti.

Technologies for decarbonizing metal production



(Material Economics, 2018)

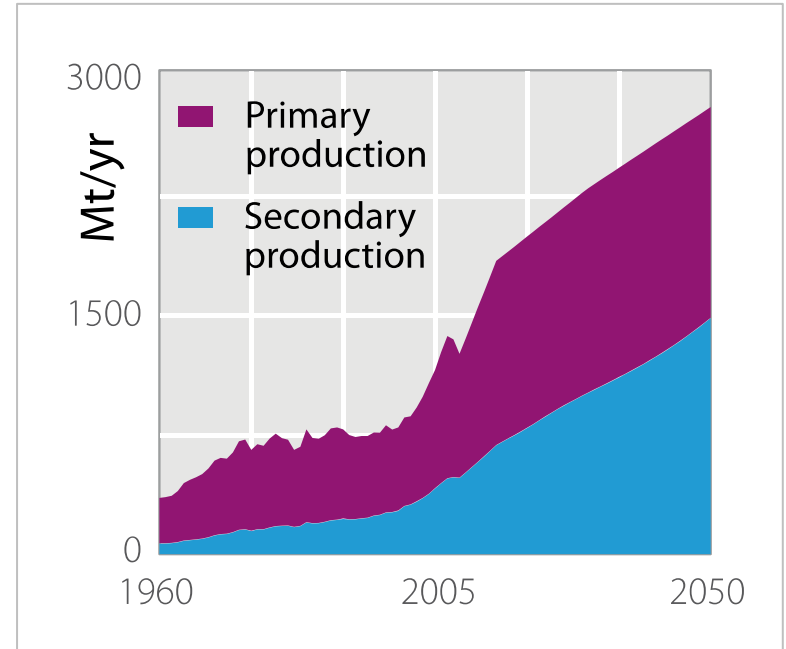
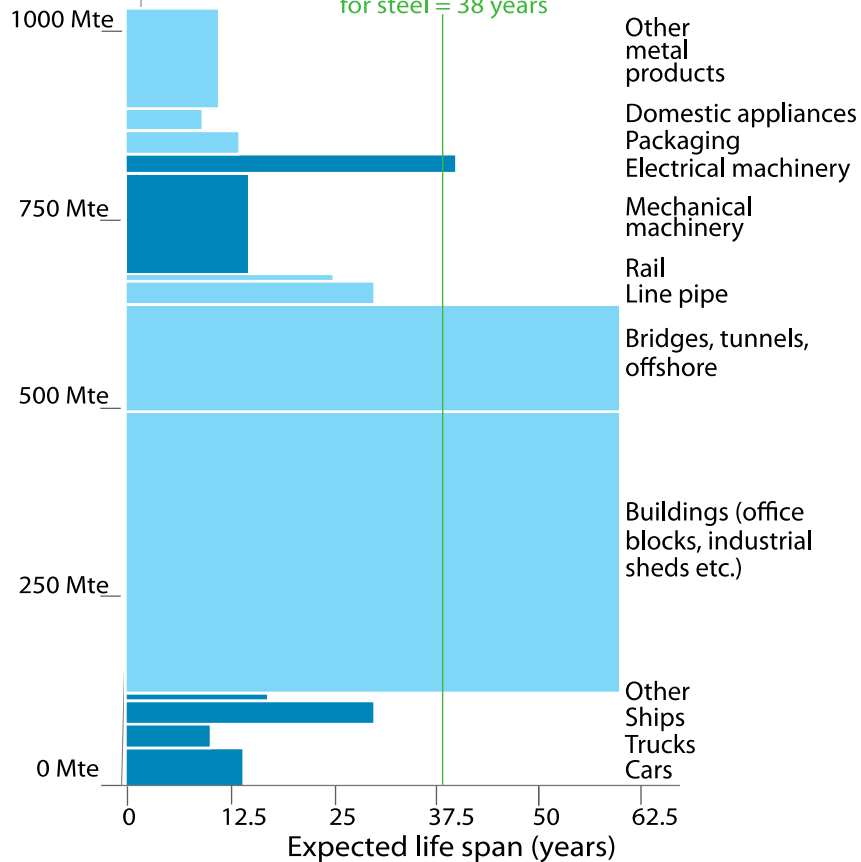
Materials innovations towards decarbonization of materials production, *in press* (2021). Daehn, Ravi, Gregory, Berlinger, Somjit, Olivetti.

Increasing scrap availability

Global tonnage (2008)

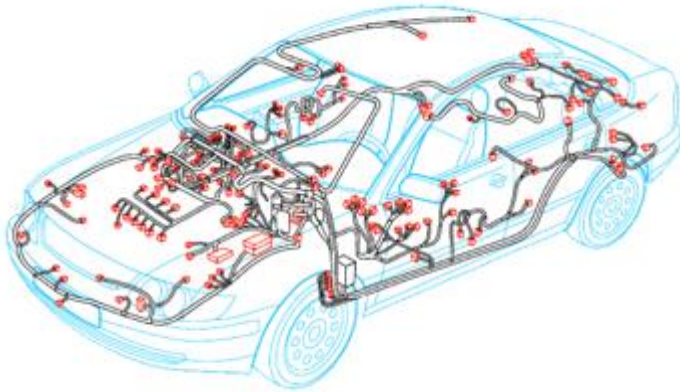
Steel end use = 1025 Mte/year

Average life expectancy
for steel = 38 years



The future of steel: time to wake up (2016), Allwood

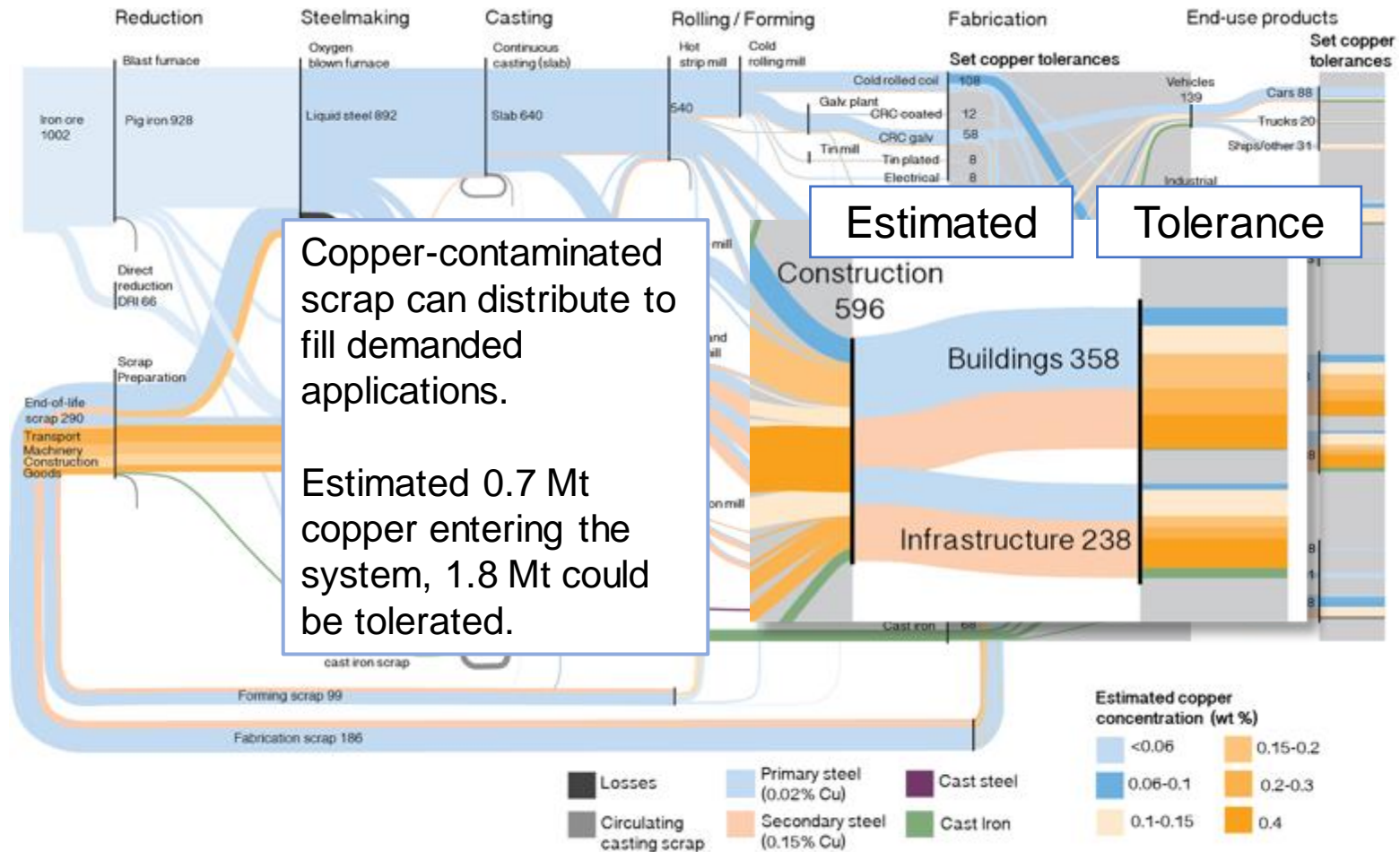
Technical barrier to increased recycling: copper contamination



Steel Grade	Interstitial Free	Deep Drawing Quality	Drawing	Commercial	Structural	Fine Wire	Rebar
Maximum Allowable Cu (wt %)	0.03	0.04	0.06	0.1	0.12	0.07	0.4

(Schrade et al., 2006)

Copper in the 2008 global steel system



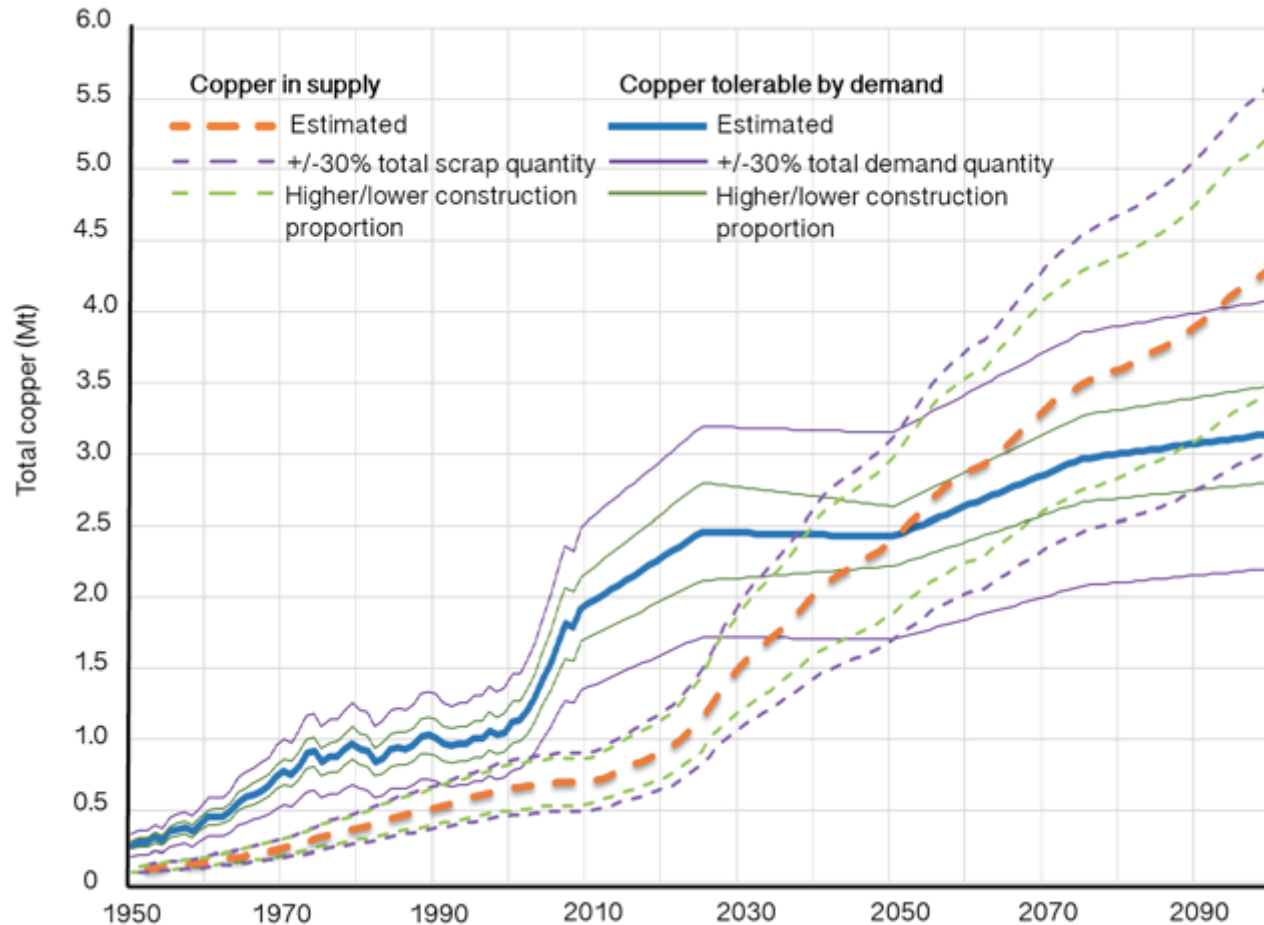
Copper-contaminated scrap can distribute to fill demanded applications.

Estimated 0.7 Mt copper entering the system, 1.8 Mt could be tolerated.

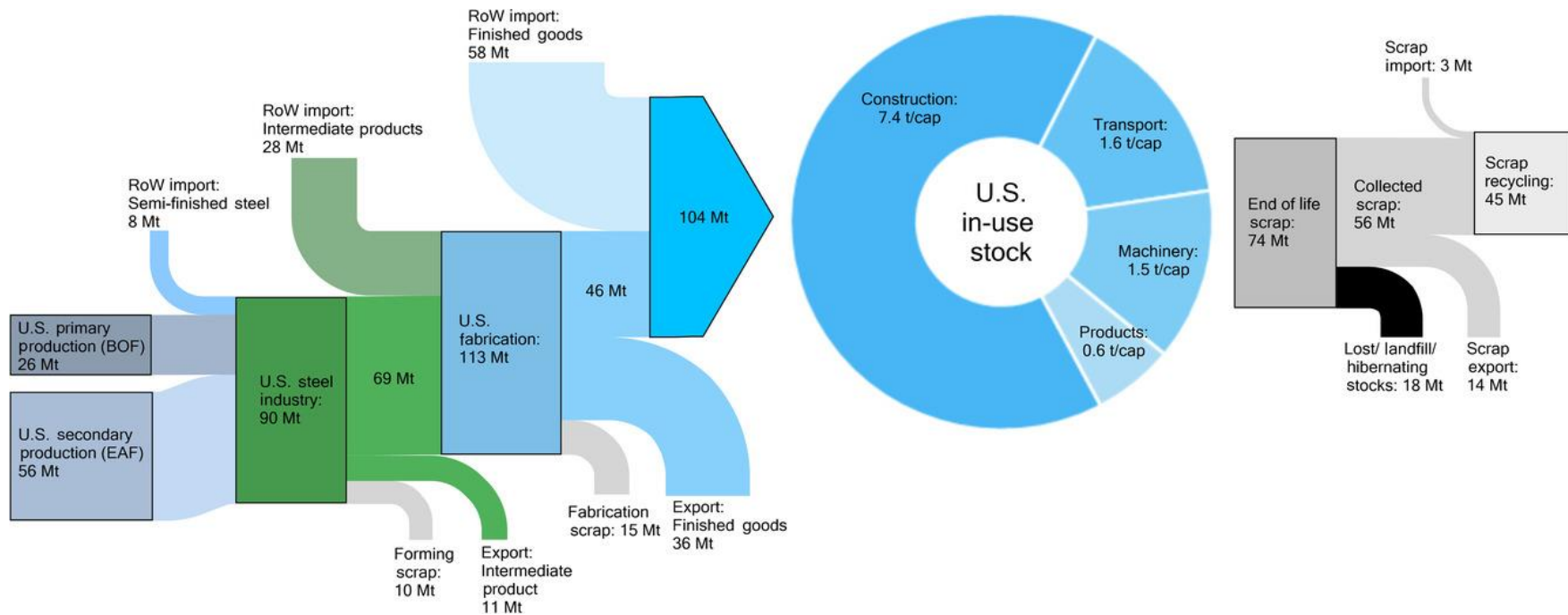
Estimated

Tolerance

Copper in the future global steel system

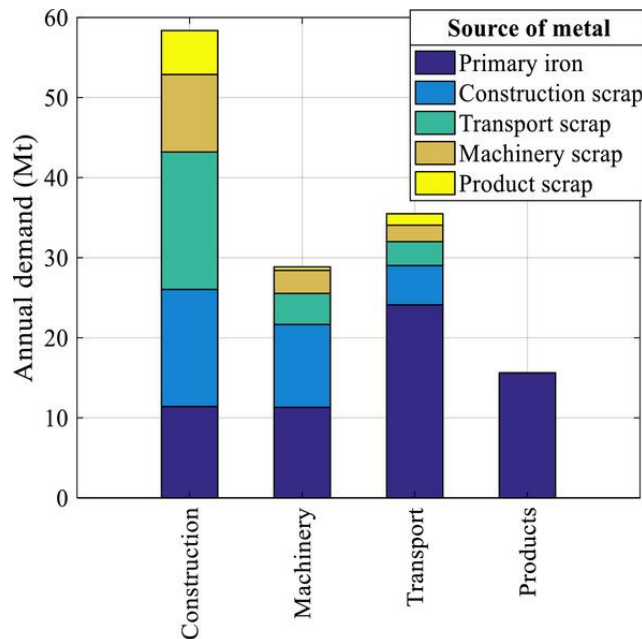


U.S.: ready for circularity?

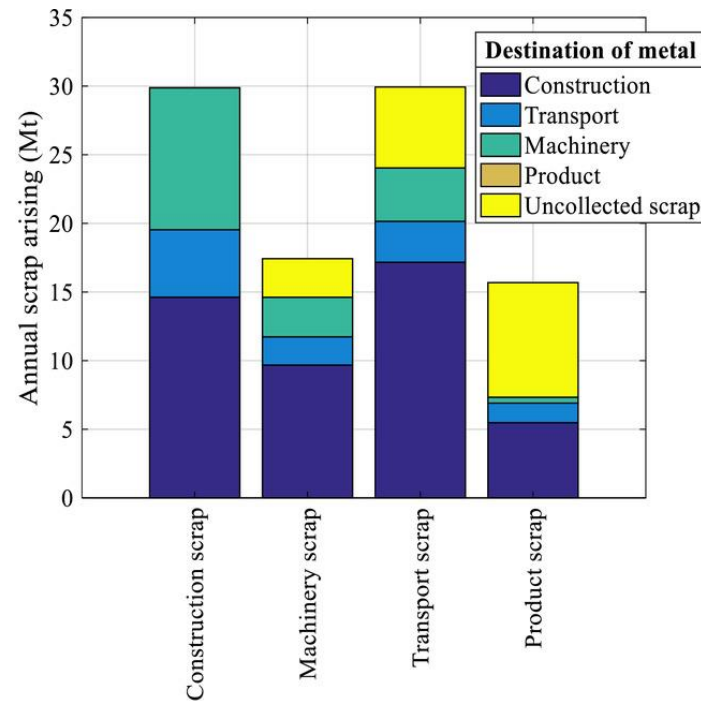


The potential for material circularity and independence in the US steel sector (2020). Cooper et al.

2050 recycling scenario in U.S. steel system



Consumption category
→
Decreasing copper tolerance
Increasing use of primary metal



Source of metal
→
Increasing copper content
Increasing quantities of uncollected scrap

The potential for material circularity and independence in the US steel sector (2020). Cooper et al.

So, what to do to better control copper?

Carmaker Delay → Scrap processor → Steelmaker



No incentive



No incentive

Batch Pre-heat Melt Cast
Extraction process Ameliorate hot shortness



Feasibility?



Limits product range

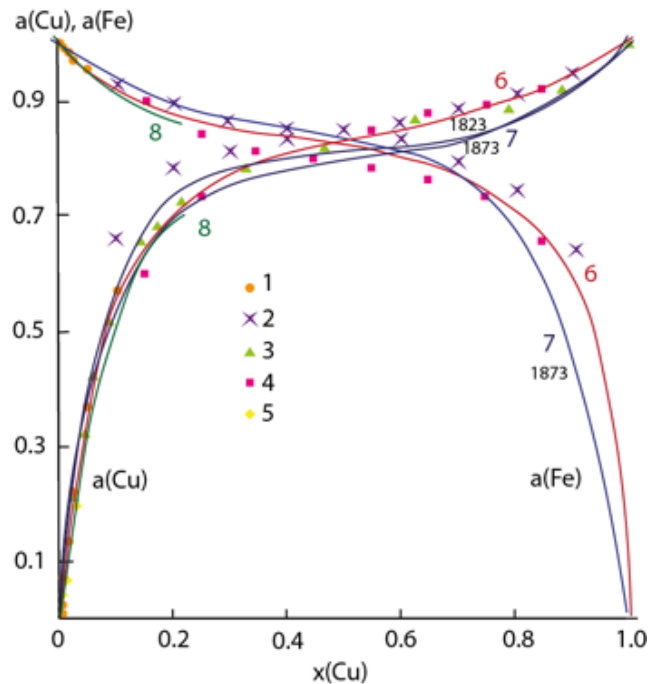
Incentive: Sell high-quality steel

Can copper be removed?

Process-independent thermodynamics: Yes, easily.

Liquid iron-copper system at 1550°C.

Activities of copper and iron:

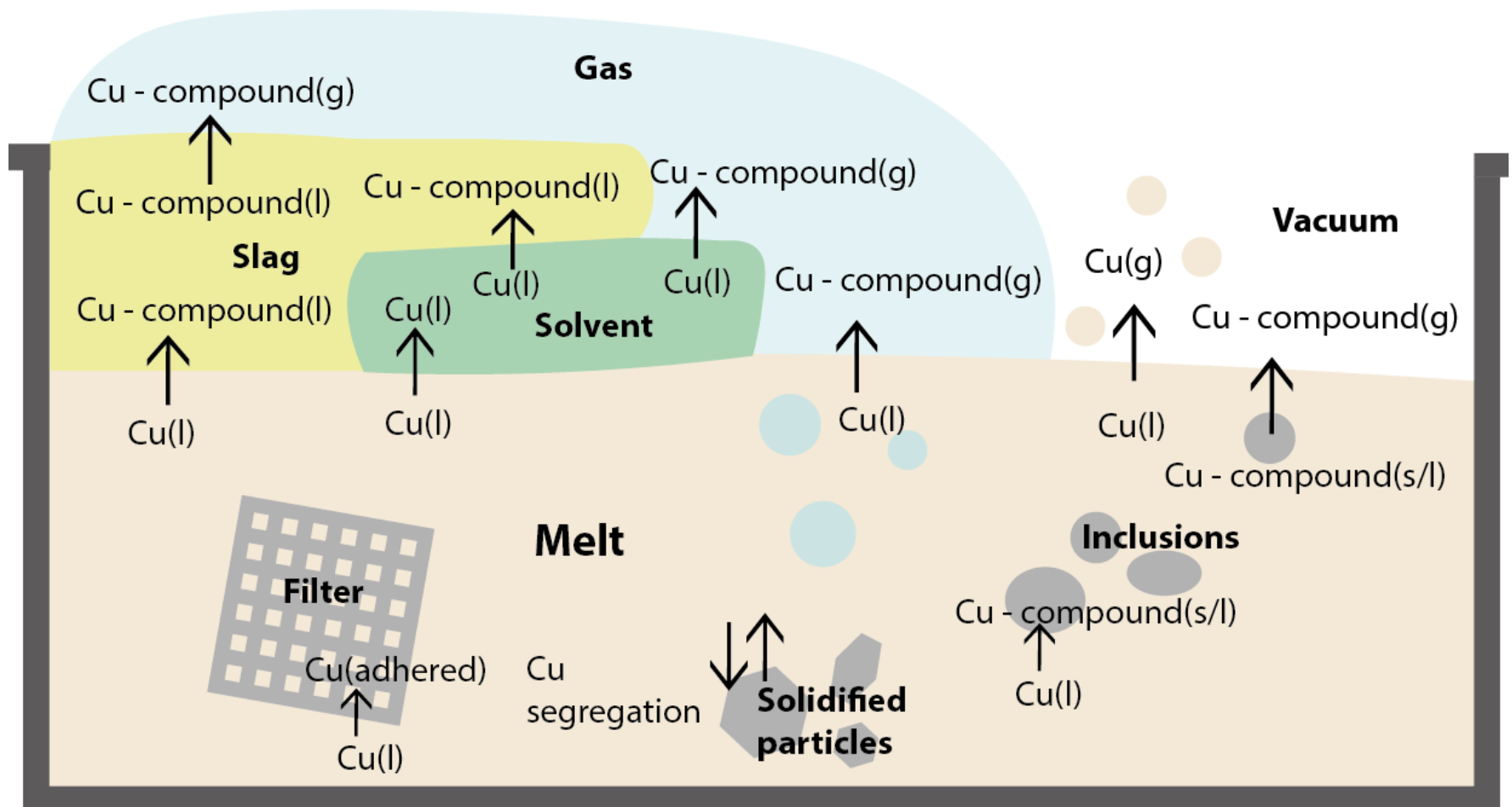


Copper and iron are not strongly interacting.

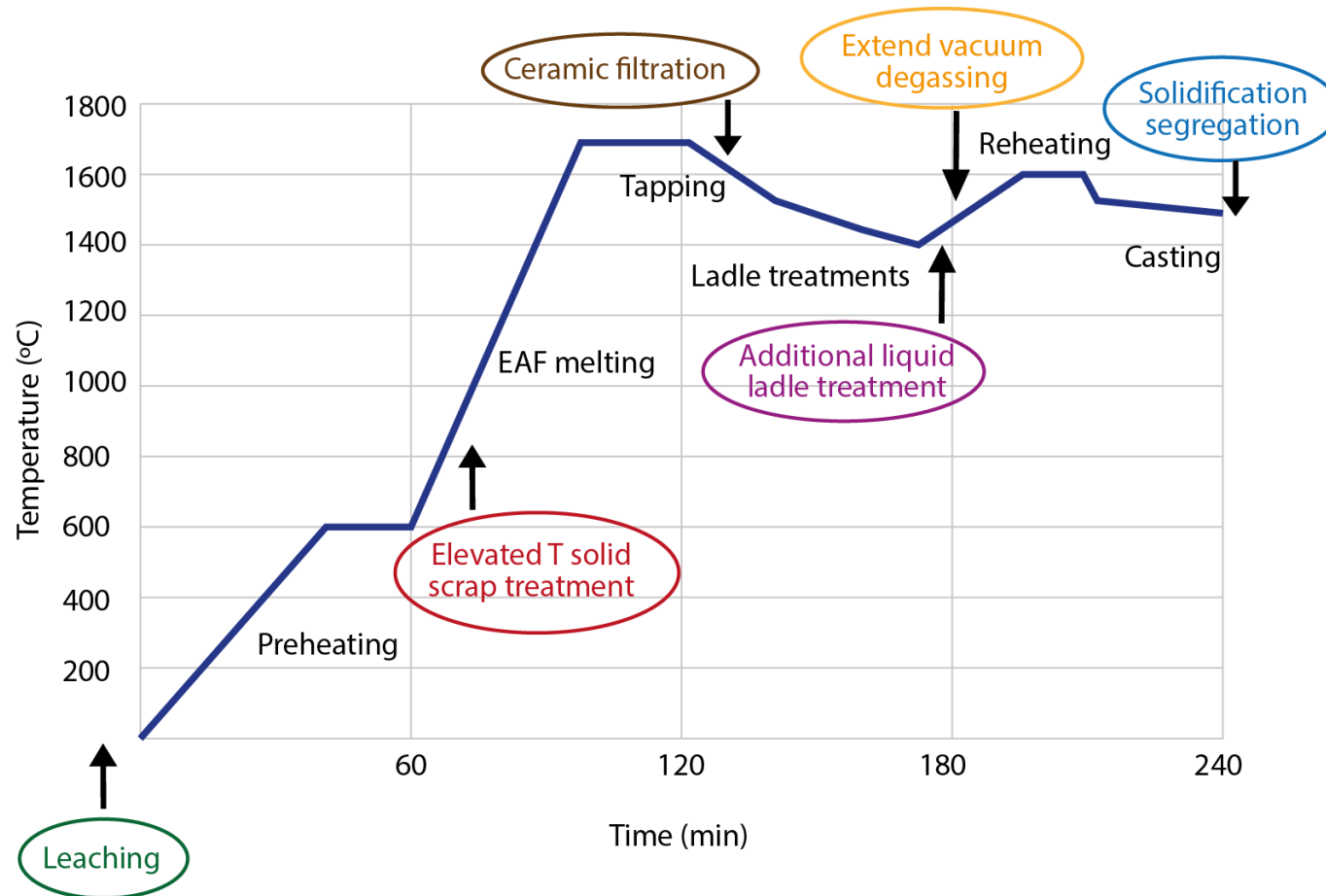
To overcome ΔG_f from 0.4wt% to 0.1wt%, amounts to ~1kWh/tonne.

Redrawn, original figure from (Zaitsev et al., 2001)

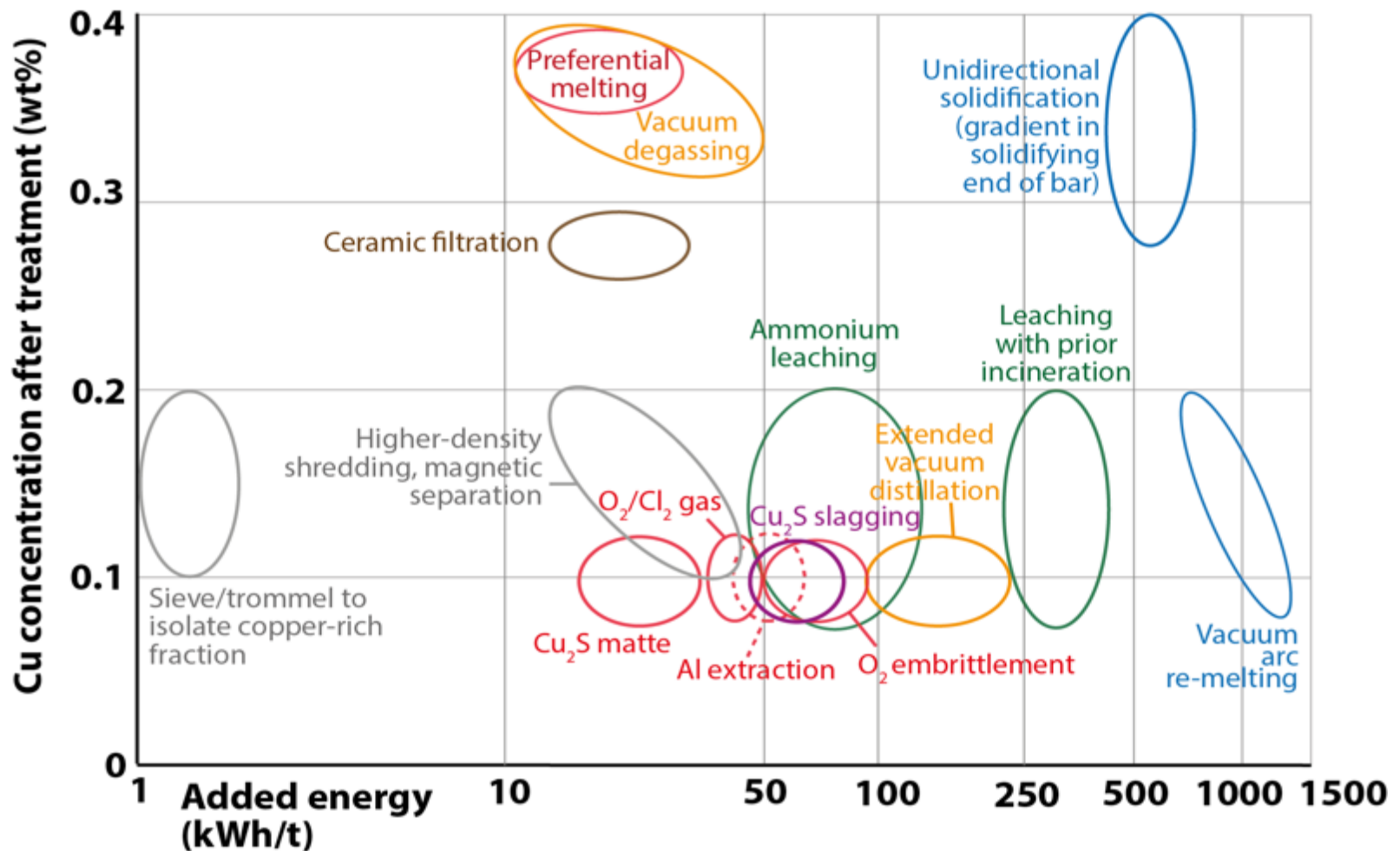
Many potential processes



Fit into steelmaking

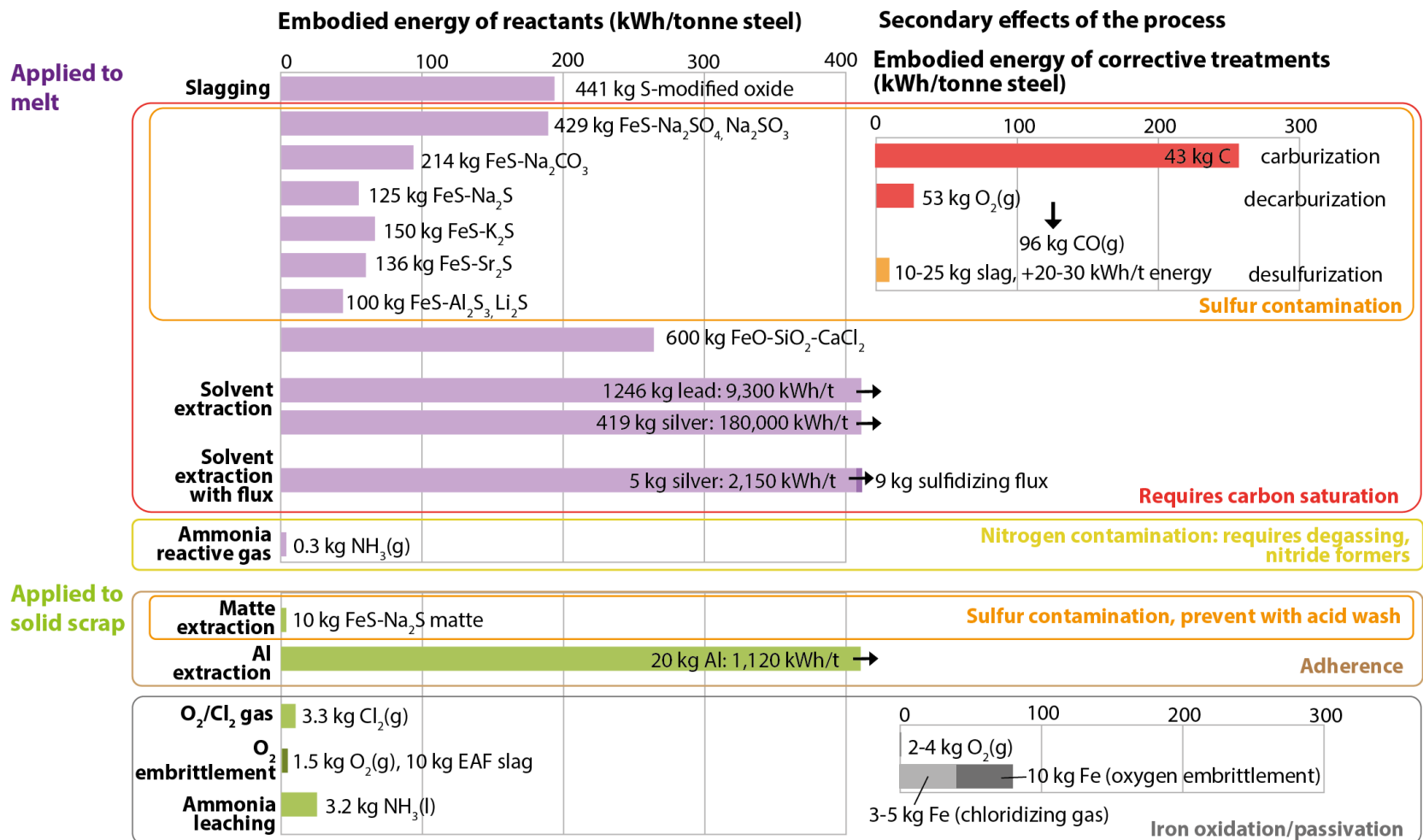


Energy required to remove copper



Finding the most efficient way to remove residual copper from end-of-life steel scrap. Daehn et al. (2019)

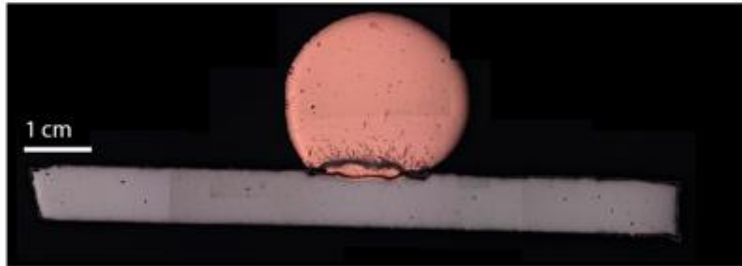
Process specific material consumption



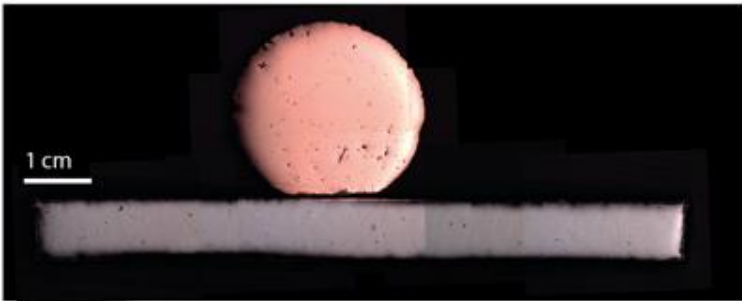
Simple melting could work...

Low carbon

Oxidized



Polished



Medium carbon

Oxidized



Polished

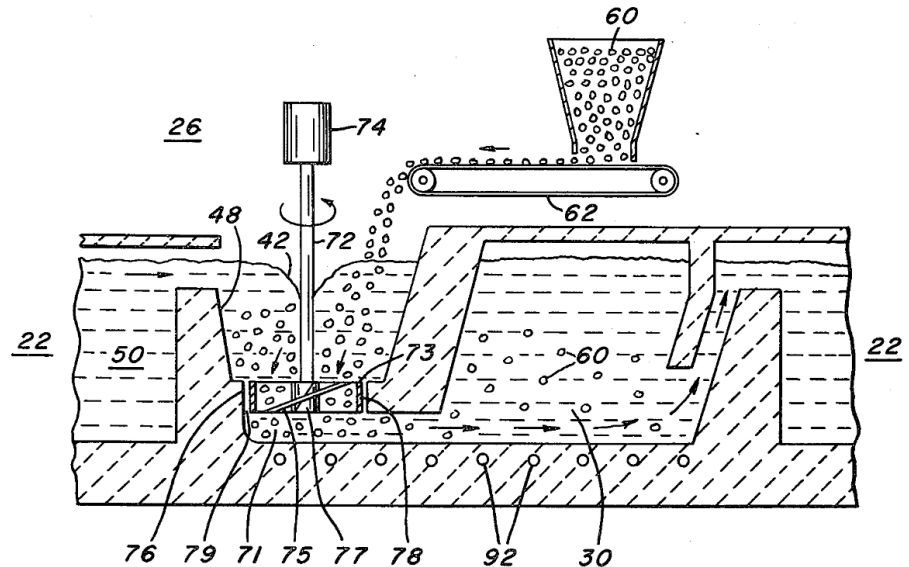
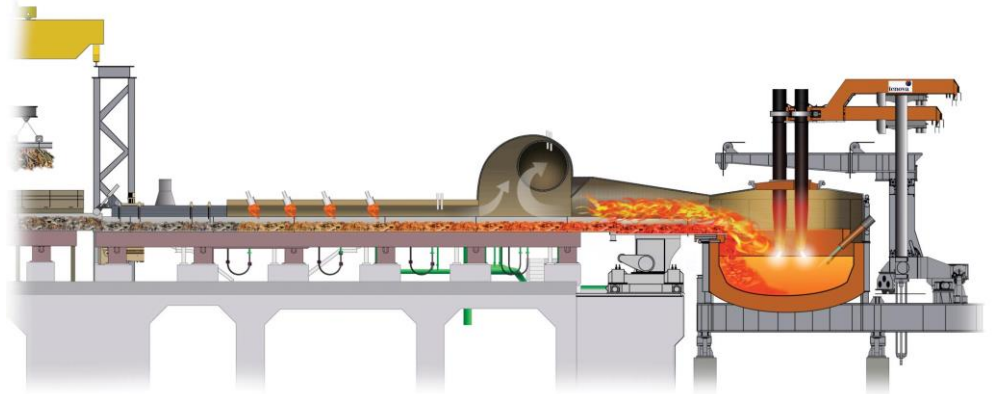


(Daehn et al., 2019)

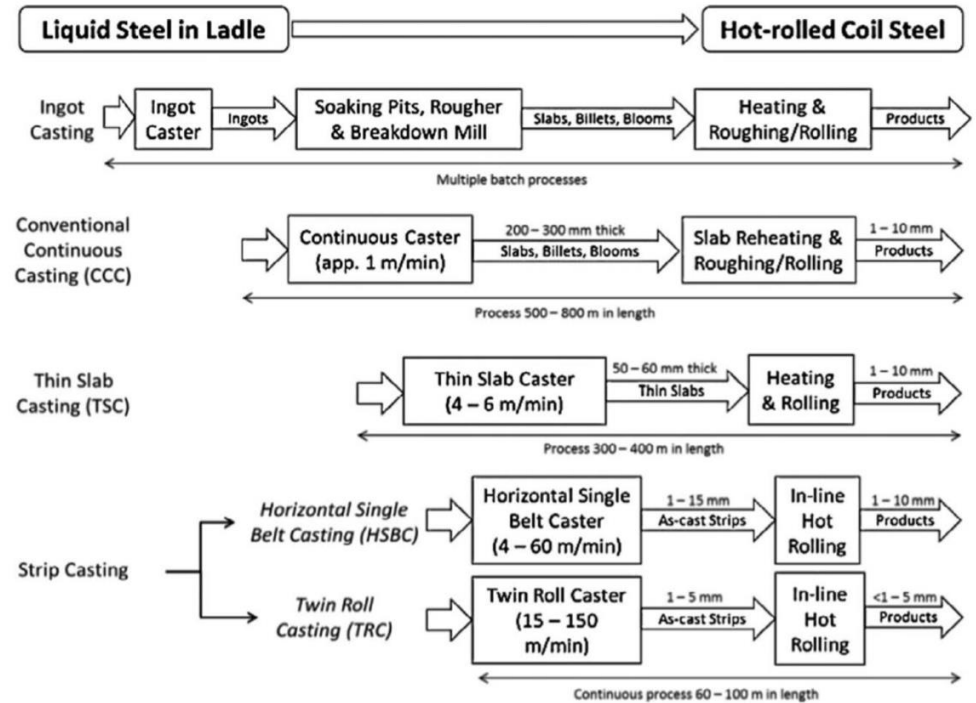
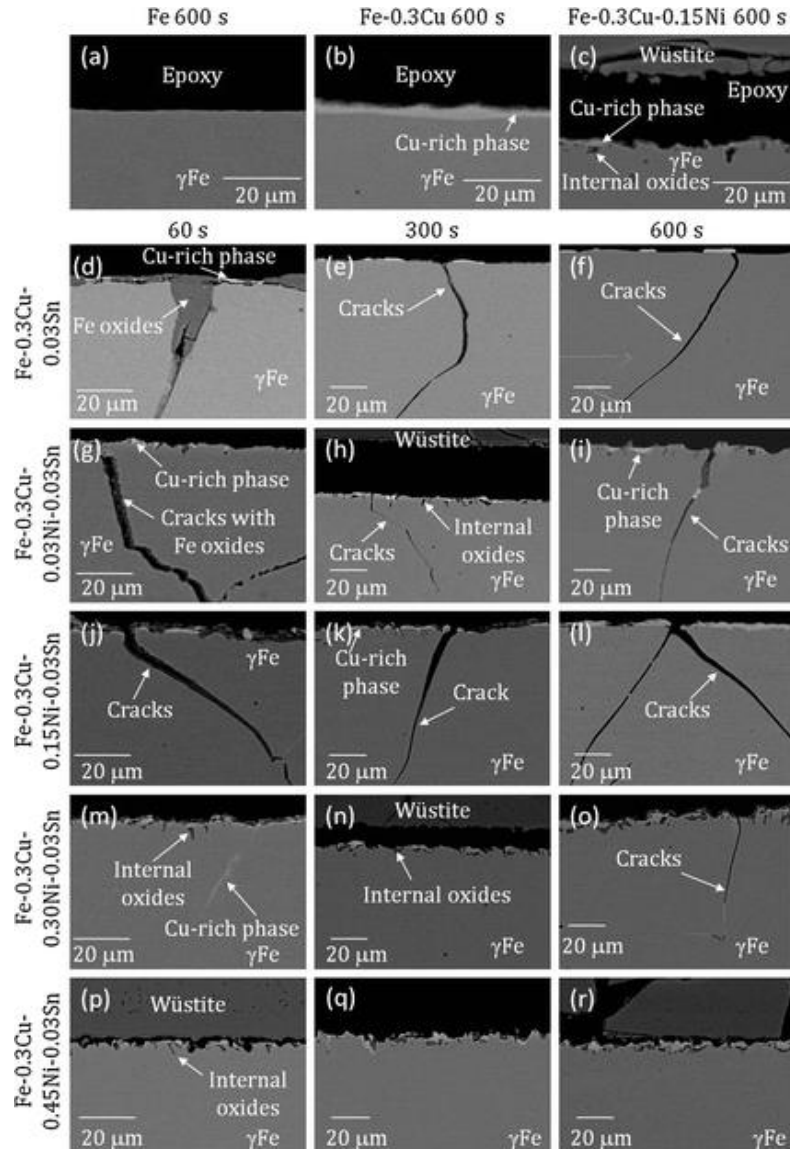
Process development

Control the oxygen/carbon potential of the atmosphere during pre-heating for recovery of liquid copper

Scrap pre-heating conveyors increase productivity, save energy.



Or, control conditions to avoid hot shortness



Ge et al. (2012). Progress of Strip Casting Technology for Steel; Historical Developments.

Yin et al. (2011). The Effects of Nickel/Tin Ratio on Cu Induced Surface Hot Shortness in Fe

My key points

- Same service could be delivered with less steel. 20% or more demand reduction from BAU is realistic.
- Steel recycling is certain to grow: may exceed primary production globally by mid-century.
- US steel system could be 'circular' this decade with appropriate measures.
 - Copper is a significant, but manageable constraint.

Acknowledgements



THE USE | LESS GROUP
LIVING WELL WHILE USING LESS



Olivetti Group

MIT | Dept. of Materials Science & Engineering

